



An Optimal Irrigation Scheduling for Drip Irrigated Onion in A- Semi-Arid Region Using the Computer Program CROPWAT 8.0

**P. R. Anjitha Krishna^{1*}, B. Maheshwara Babu¹, A. T. Dandekar²,
R. H. Rajkumar¹, G. Ramesh¹ and S. R. Balanagoudar³**

¹Department of Soil and Water Engineering, College of Agricultural Engineering, University of Agricultural Sciences, Raichur, India.

²College of Agriculture, VC Farm, Mandya, University of Agricultural Sciences, Bangalore, India.

³Department of Soil Science and Agrl. Chemistry, College of Agriculture, University of Agricultural Sciences, Raichur, India.

Authors' contributions

This work was carried out in collaboration among all authors. Author PRAK performed the field experiment, obtained field observations, performed the statistical analysis and wrote the first draft of the manuscript. Authors BMB, ATD and RHR helped to design the experiment and experimental analyses of the study. Authors GR and SRB managed the literature searches and corrected the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Efficient utilization of available water resources requires appropriate management strategies considering the changing environmental conditions. The present study used a widely adopted crop water requirement estimation model-CROPWAT 8.0 for estimation and scheduling of irrigation requirement for onion crop grown under Vertisol in the Rabi season in the semi-arid region of Raichur district. The soil moisture at the root zone was not allowed to fall below 50% depletion. The irrigation events brought the soil moisture back to the field capacity level. The total water requirement for the 1st and 2nd seasons was 428.77 mm and 399.98 mm respectively at 90% irrigation efficiency. CROPWAT based two days irrigation scheduling scenario was found to be appropriate to maintain optimal soil moisture range within the crop root zone at different crop stages.

*Corresponding author: E-mail: anjithakrishna100@gmail.com;

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1. INTRODUCTION

The current world's population of 7800 million is expected to increase to around 8100 million by 2030, which will result in considerable increase in demand for food. Simultaneously the demand for water from non-agricultural sectors will also keep growing in both developing and developed countries. About 40% of the land in the world is under arid and semi-arid climatic conditions. The declining availability of fresh water has become a worldwide problem, especially in arid and semi-arid region regions, where irrigation practices are necessary to meet the crop production El-Wahed et al. [1]. In the past decade there has been a tremendous growth in the irrigated area through drip system. Currently about 351000 ha area is under drip irrigation in India. Maharashtra, Karnataka, and Tamil Nadu are the leading states in terms of area under drip irrigation in India. The National Committee on Plastics Applications in Horticulture (NCPAH), Ministry of Agriculture and Farmers Welfare, Govt. of India estimated that a total of 27 M ha of land in the country holds the potential to be brought under drip irrigation.

The rainfed crop production and conservation of irrigation water can be improved with better knowledge on crop water requirements Jensen et al. [2]. An optimum irrigation scheduling provides optimum quantity of water at the right time maintaining water use efficiency without compromising the yield. CROPWAT is a decision support tool developed by Land and Water Development division of FAO, being widely used for estimating irrigation water requirement considering the meteorological, crop as well as soil parameters Smith, [3]. Various studies have been conducted in different parts of India recommending the use of the model for irrigation scheduling applications Saravanan and Saravanan [4]; Naik et al. [5]; Surendran et al., [6]; Mehanuddin et al. [7] and Shekhar et al. [8]. The present study employed CROPWAT 8.0 model for scheduling irrigation of onion crop grown during Rabi season (September-March) and the moisture distribution status in the crop root zone was monitored in different crop growth stages.

2. MATERIALS AND METHODS

2.1 Experimental Setup

The experiment was conducted during September-March (*rabi*) in both 2018-19 and

2019-20 in Raichur district, Karnataka, India (16°12' 8.68" N and 77°19' 47.97" E). The soil in the study area belongs to sandy clay texture with pH 7.81, EC 1.38 dS m⁻¹, bulk density 1.51 g cm⁻³, field capacity 42.38% and permanent wilting point 21.93%. The seedlings were transplanted at 47 days after sowing (DAS) on to the beds at 15 cm×10 cm spacing on 12th November, 2018 in the first season and on 4th November, 2019 in the second season. The experiment was laid out in split plot design with three replications. The experiment consisted of three levels of mulching conditions (paddy straw mulch (M₁), white plastic mulch (M₂) and control (M₃)) as main treatment and three levels of fertigation (50% (F₁), 75% (F₂) and 100% (F₃) of recommended dose of fertilizers) as sub treatments replicated thrice.

2.2 Hydraulics of Drip System

After the installation of drip fertigation setup, a sub experiment was conducted in the field to analyze the hydraulic performance of the installed drip irrigation system before transplanting of crop. By monitoring dripper discharge rates with measuring cans, four widely used parameters representing the emitter discharge uniformity were determined as follows.

(i) Average emitter discharge (q_{avg})

The volume of water collected in individual catch cans within known time was used to find out the actual discharge rate of the emitter in an hour (lph) (Eq. (1)). The average discharge rates thus calculated could be used in scheduling the irrigation.

$$q_{avg} = \frac{1}{n} \sum_{i=1}^n q_i \quad \text{Eq. (1)}$$

Where,

q_{avg}=Average emitter flow rate;
q_i=Individual emitter discharge measurements;
n=Number of observations.

(ii) Emitter flow variation, q_{var}

It was calculated using the eq. (2) Camp et al., [9]:

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}} \times 100 \quad \text{Eq. (2)}$$

Where,

q_{max} =Maximum emitter flow rate;
 q_{min} =Minimum emitter flow rate.

(iii) Coefficient of variation, CV

It is given by eq. (3) and eq. (4):

$$S = \sqrt{\frac{\sum_{i=1}^n q_i^2 - \frac{1}{n}(\sum_{i=1}^n q_i)^2}{n-1}} \quad \text{Eq. (3)}$$

$$CV = \frac{S}{q_{avg}} \quad \text{Eq. (4)}$$

Where,

S=Standard deviation;
 n=Number of observations;
 q_{avg} =Average emitter flow rate (Eq. (1));

Coefficient of variation of less than 0.05 is rated as excellent; 0.05 to 0.07 is rated as average; 0.07 to 0.11 is rated as marginal; 0.11 to 0.15 is rated as poor; and above 0.15 is rated as unacceptable Michael, [10].

(iv) Uniformity coefficient (UC)

This parameter is defined by Christiansen [11], and the same was modified further by many others for expressing the same in percentage as given in eq. (5) Camp et al., [9]; Michael, [10]:

$$UC = 100 \left[1 - \frac{\frac{1}{n} \sum_{i=1}^n |q_i - q_{avg}|}{q_{avg}} \right] \quad \text{Eq. (5)}$$

Where, n=Number of emitters evaluated.

(v) Distribution uniformity (DU)

It was given by Kruse [12] as below in eq. (6):

$$DU = 100 \frac{q_{avg(lq)}}{q_{avg}} \quad \text{Eq. (6)}$$

Where,

$q_{avg(lq)}$ =Mean of lowest one-fourth of emitter flow rates;
 q_{avg} =Mean emitter flow rate.

A DU value of less than 60% appears to be lower for delicate crops Keller and Bleisner, [13].

2.3 Irrigation Scheduling

Crop water requirement during the experimental seasons were determined with the help of

CROPWAT 8.0 model. The reference evapotranspiration (ET_0) was estimated by FAO-56 Penman Monteith formula Allen et al. [14]. Meteorological data of Raichur was collected from Main Agricultural Research Station (MARS), University of Agricultural Sciences, Raichur for 2013 to 2020 on daily basis. The ET_0 was estimated for past five years and five year average crop water requirement was taken for irrigation scheduling. CROPWAT 8.0 requires daily data on minimum temperature, maximum temperature, humidity, wind speed, and sunshine hours, monthly data on rainfall, crop data (i.e. planting date, crop coefficient values for four different growth stages and number of days under each growth stage, rooting depth, critical depletion fraction, yield response factor, and crop height), and soil data (i.e. total available soil moisture, saturated hydraulic conductivity, and initial soil moisture depletion). The crop parameters for onion are not included in CROPWAT 8.0 database. The model parameters were obtained from literatures and field study. The crop water requirement was calculated using eq. 7 and eq. (8).

$$ET_c = K_c \times ET_0 \quad \text{Eq. (7)}$$

$$CWR = ET_c - P_{eff} \quad \text{Eq. (8)}$$

Where

ET_c =Crop evapotranspiration ($cm\ d^{-1}$);
 K_c =Crop coefficient;
 ET_0 =Reference evapotranspiration ($cm\ d^{-1}$);
 CWR =Crop water requirement ($cm\ d^{-1}$);
 P_{eff} =Effective rainfall ($cm\ d^{-1}$).

USDA Soil Conservation Service (SCS) method was used for determining effective rainfall. The irrigation requirement in litre per day was computed from crop specific gross irrigation requirement estimated by the model (in $mm\ day^{-1}$) and the irrigated soil surface area by using eq. (10) Smith, [3]. The duration of irrigation was calculated using eq. (11) Gärdenäs et al. [15].

$$Q_{req} = \frac{CWR \times d \times w}{1000} \quad \text{Eq. (10)}$$

$$\text{Duration of irrigation} = \frac{Q_{req} \times 60}{q_{avg} \times \text{efficiency of drip system}}$$

Eq. (11)

Where,

Q_{req} =Irrigation requirement ($l\ d^{-1}$);
 d =Emitter distance (cm);

w =Lateral spacing (cm);
 q_{avg} =Average emitter discharge rate, lph.

The wetting radius for one day irrigation scheduling was not sufficient to reach upto crop rows in the middle of the beds, hence irrigation scheduling was done for 48 hours interval (except on Sundays), starting with the date of first irrigation after transplanting. The last day of irrigation was fixed two weeks before the scheduled harvesting date for reducing storage losses of onion Vitnor et al. [16]. The soil moisture at the root zone was not allowed to fall below 50% of available soil moisture. Each irrigation event was designed to maintain the soil moisture between 50% of available soil moisture and the field capacity.

Soil moisture in the root zone of the onion crop was monitored at 30, 60 and 90 days after transplanting (DAT) of crop from 0-20 and 20-40 cm soil depths. The samples were then dried inside the hot air oven at 105°C for 36 hrs for the determination of soil moisture.

2.4 Statistical Analysis

The parameters of hydraulics of drip system was analyzed statistically using the split plot design. The significance of each of the results was estimated at 5% level of significance. The calculations were done with the help of "MS excel" software.

3. RESULTS AND DISCUSSION

3.1 Performance Evaluation of Drip Irrigation System

The average emitter discharge (q_{avg}) in the straw, plastic, and control treatments were 1.91, 1.89 and 1.81 lph, respectively during 2018-19 and 1.41, 1.42 and 1.37 lph, respectively in 2019-20. The emitter flow variation (q_{var}) below 20% is acceptable Mistry et al. [17]. The emitter flow variation during 2018-19 was below 20% in all the treatment beds (Table 1). The flow variations in the treatments increased in 2019-20. The average emitter flow variation in straw mulched, plastic mulched and non-mulched (control) beds were 12.68, 6.88 and 9.29%, respectively in 2018-19 and 19.92, 14.83 and 19.69%, respectively, in 2019-20 (Table 2).

The coefficient of variation of flow (CV) was \leq 0.05 with almost excellent performance in all the treatments. In 2019-20, the CV values were

increased upto 0.136 in certain treatments due to poor performance of drip system. CV value above 0.15 is unacceptable Michael [10]. The average CV values for the straw, plastic mulch, and control treatments were 0.034 (excellent performance), 0.024 (excellent performance), and 0.033 (excellent performance), respectively in 2018-19 and 0.076 (marginal performance), 0.05 (average performance), and 0.068 (average performance), respectively in 2019-20. Ramalan et al. [18] also reported the same results.

The uniformity coefficient (UC) for all the treatments was above 95 and 87% against the satisfactory limit of \geq 85%, in 2018-19 and 2019-20, respectively under all the treatments. The distribution uniformity (DU) ranged between 92 and 99% in 2018-19 indicating excellent uniformity of water application. However, in 2019-20, the values ranged between 87 and 97% indicating fair to excellent range of uniformity of water application Keller and Bleisner [13] and Priya et al. [19]. The drip lines were not subjected to acid treatment in the second season (2019-20). The declined performance of the drip system in the second season might have occurred due to the partial clogging of the emitters from suspended solids in irrigation water as reported by Camp et al. [9]. The average hydraulic characteristics were within the acceptable limits in both the seasons. The duration of irrigation was scheduling considering the performance of the drip system.

3.2 Scheduling of Irrigation with CROPWAT

The duration of irrigation varied between 14 to 18 min in 2018-19 and 20 to 27 min in 2019-20 upto 30 DAT. Thereafter upto 90 DAT, the duration was 20 to 27 min in 2018-19 and 25 to 33 min in 2019-20. In later stages of crop the duration increased to 28 to 33 min in 2018-19 and 34 to 39 min in 2019-20 for two days irrigation schedule. The total water requirement during 2018-19 and 2019-20 were 428.77 and 399.98 mm, respectively (Table 3). The sowing of onion seeds in the nursery beds was done twelve days earlier and more number of rainy days helped to meet the water requirement without additional application of water during 2019-20. Also, increased temperature and higher evaporation rates during February increased the water application during 2018-19, whereas the irrigation was stopped by the first week of February during 2019-20. These factors contributed to increased water requirement during 2018-19.

Table 1. Hydraulic performance of drip irrigation during 2018-19

Treatment	Hydraulic performance indicators				
	q_{avg} (lph)	q_{var} (%)	CV	UC	DU
M ₁ F ₁	1.91	9.09	0.019	98.78	97.38
M ₁ F ₂	1.67	16.13	0.046	96.72	95.02
M ₁ F ₃	2.16	12.82	0.036	97.60	96.38
M ₂ F ₁	1.95	3.03	0.016	98.48	98.63
M ₂ F ₂	1.95	14.29	0.040	95.45	92.15
M ₂ F ₃	1.76	3.33	0.016	98.63	99.05
M ₃ F ₁	1.85	9.09	0.033	97.19	97.47
M ₃ F ₂	1.75	9.68	0.033	97.24	96.18
M ₃ F ₃	1.84	9.09	0.033	97.13	97.65
SEm+	0.004	0.005	0.001	0.007	0.004
CD (P=0.05)	0.012	0.016	0.002	0.021	0.012

Table 2. Hydraulic performance of drip irrigation during 2019-20

Treatment	Hydraulic performance indicators				
	q_{avg} (lph)	q_{var} (%)	CV	UC	DU
M ₁ F ₁	1.31	19.58	0.045	96.86	95.79
M ₁ F ₂	1.38	22.69	0.136	87.95	78.12
M ₁ F ₃	1.55	17.50	0.047	96.30	95.97
M ₂ F ₁	1.42	15.38	0.052	96.00	95.07
M ₂ F ₂	1.42	13.73	0.049	95.99	94.53
M ₂ F ₃	1.43	15.38	0.050	95.79	94.57
M ₃ F ₁	1.30	22.00	0.069	95.76	92.49
M ₃ F ₂	1.47	24.57	0.105	90.08	87.37
M ₃ F ₃	1.34	12.51	0.031	97.59	97.20
SEm+	0.01	0.02	0.001	0.020	0.007
CD (P=0.05)	0.017	0.062	0.002	0.061	0.021

(Note: q_{avg} -average emitter discharge (lph); q_{var} -emitter flow variation (%); CV-coefficient of variation; UC-uniformity coefficient; DU-distribution uniformity; SEM-standard error of mean; CD-critical difference)

Main treatments (M): M₁: Paddy straw mulch; M₂: White plastic mulch; M₃: Control (without mulching)

Sub treatments (F): F₁: Fertigation with 50% RDF; F₂: Fertigation with 75% RDF; F₃: Fertigation with 100% RDF

Table 3. Irrigation water application in entire crop period during 2018-19 and 2019-20

Irrigation water applied	Season-I	Season-II
	(2018-19)	(2019-20)
Raising the seedlings in the nursery (mm)	19.00	12.00
Wetting of the beds before transplanting (mm)	37.40	28.00
Water applied through drip irrigation (mm)	372.37	359.98
Total amount of irrigation water applied (mm)	428.77	399.98

Table 4. Water application in different crop growth stages

Crop growth stages	Irrigation water applied (mm)	
	Season-I (2018-19)	Season-II (2019-20)
Initial (52 days)	61.37	40.00
Development (50 days)	156.44	156.73
Mid-season (30 days)	144.88	130.92
Late season (30 days)	66.08	72.33
Total amount of irrigation water applied (mm)	428.77	399.98

The amount of water applied in the month of September and October constituted water requirement for the crop nursery. The water requirement for the wetting of the raised beds before transplanting of the seedlings and prolonged irrigation for two days after transplanting for better crop establishment, were included in the month of November. The amount of water applied was highest in January in both the season, i.e. 141.44 and 144.72 mm during 2018-19 and 2019-20, respectively. The higher crop coefficient values and increased day time temperatures during last weeks of January increased the water requirement compared to December. The higher crop coefficient values and increased time period (50 days) resulted in highest water application in the development stage of the crop, i.e. 156.44 and 156.73 mm during 2018-19 and 2019-20, respectively (Table 4). The same amount of water was applied in all the treatments at the same day. The reported crop water need of onion was 350-550 mm Allen et al. [14] and the estimate in the study is in conformity with the reported data.

3.3 Soil moisture Distribution during Irrigation

3.3.1 Paddy straw treatments

The soil moisture before irrigation varied from 0.35-0.37 $\text{cm}^3\text{cm}^{-3}$ in the upper 0-20 cm soil layer beneath drip emitter. At three hours after the irrigation the soil moisture increased to 0.39-0.41 $\text{cm}^3\text{cm}^{-3}$. The soil moisture varied from 0.37 to 0.38 $\text{cm}^3\text{cm}^{-3}$ and 0.36 to 0.37 $\text{cm}^3\text{cm}^{-3}$ at 24 and 48 hours after irrigation, respectively. The lateral and downward movement of soil moisture might have resulted in its depletion. At 15 cm away from the emitter, in the upper soil layer (0-20 cm), the soil moisture increased to 0.37-0.38 $\text{cm}^3\text{cm}^{-3}$ at three hours after the irrigation and then depleted to 0.36-0.37 $\text{cm}^3\text{cm}^{-3}$ and 0.34-0.35 $\text{cm}^3\text{cm}^{-3}$ at 24 and 48 hours after the irrigation, respectively.

At the 20-40 cm soil layer under the drip emitter, the soil moisture increased to 0.37-0.38 $\text{cm}^3\text{cm}^{-3}$ at 3 hours after the irrigation. At 24 and 48 hours after the irrigation the soil moisture varied from 0.36 to 0.37 and 0.36 to 0.37 $\text{cm}^3\text{cm}^{-3}$ respectively. At the same soil layer 15 cm away from the emitter the soil moisture remained almost same though there was a slight increase in soil moisture content at 48 hours after the irrigation at 30 and 60 DAT and soil moisture depleted slightly at 90 DAT. The reduced root

water uptake (as the density of roots was concentrated within 25 cm from the top) and evaporation may be the reason for reduced depletion of soil moisture from the 20-40 cm soil layer. The irrigation events kept the soil moisture within 50% depletion of available soil moisture range during the irrigation interval of 48 hours (Fig. 1).

3.3.2 Plastic mulch treatments

The soil moisture increased to 0.36-0.41 $\text{cm}^3\text{cm}^{-3}$ in the upper soil layer (0-20cm), under the emitter at three hours after the irrigation. The soil moisture depleted to 0.35-0.39 and 0.33-0.37 $\text{cm}^3\text{cm}^{-3}$ at 24 and 48 hours after the irrigation respectively in different crop growth stages. At 15 cm away from the emitter in the same soil layer, the soil moisture increased to 0.35-0.39 $\text{cm}^3\text{cm}^{-3}$ at three hours after the irrigation and depleted to 0.34-0.38 $\text{cm}^3\text{cm}^{-3}$ and 0.33-38 $\text{cm}^3\text{cm}^{-3}$ at 24 and 48 hours after the irrigation, respectively.

At 20-40 cm depth under the emitter, the soil moisture increased to 0.32-0.38 $\text{cm}^3\text{cm}^{-3}$, three hours after the irrigation and there after decreased to 0.32-0.38 and 0.32-0.37 $\text{cm}^3\text{cm}^{-3}$ at 24 and 48 hours after the irrigation, respectively at 60 and 90 DAT. These depletions were smaller compared to depletion observed in 20-40 cm soil layer in the paddy straw mulched treatment due to prevention of sub soil evaporation. In the 20-40 cm soil layer 15 cm away from the emitter, the soil moisture was increasing by a very lower rate after irrigation upto 48 hours of observation. The soil moisture status in different soil layers increased from 30 to 90 DAT in the plastic mulched treatment. The irrigation events maintained the soil within 50% depletion of available soil moisture range. The upper soil layer 15 cm away from emitter depleted to 41.8% of available soil moisture range, during 30 DAT due to decreased initial moisture condition at the starting period of simulation in the plastic mulched plots, but thereafter remained within the 50% depletion of available soil moisture range at 60 and 90 DAT due to accumulation of soil moisture due to reduced evaporative loss (Fig. 2).

3.3.3 Control treatments

At the top soil layer (0-20 cm) below the emitter, the soil moisture increased to 0.35-0.40 $\text{cm}^3\text{cm}^{-3}$, 3 hours after the irrigation event in different crop growth stages. The soil moisture then depleted to 0.33-0.37 and to 0.31-0.35 $\text{cm}^3\text{cm}^{-3}$ within 24 and

48 hours of irrigation respectively. In the same soil layer 15 cm away from the emitter, the soil moisture increment at three hours after the irrigation was less compared to mulched treatments. There was slight increase in soil moisture content 24 hours after irrigation and then depleted thereafter in next 24 hours.

At the 20-40 cm soil layer under and 15 cm away from the emitter, the soil moisture depleted continuously, may be due to evaporative loss of moisture from sub soil layers as there is no covering on the soil surface. The soil moisture range in upper layers also depleted from 30 to 90 DAT. The capillary movement of sub soil moisture and its leaching below the simulation domain are other factors contributing to sub soil moisture depletion. There was no rainfall events during the simulation period and the evaporation losses were higher during 90 DAT compared to 30 and 60 DAT. The irrigation events kept the

soil moisture within the available soil moisture range in top 0-20 cm soil layer under the emitter, but at 48 hours after irrigation soil moisture depleted below 50% of available soil moisture range at 60 and 90 DAT, which is in agreement with the irrigation schedule scenario from the CROPWAT model.

The soil moisture in the 0-20 cm layer 15 cm away from the emitter was below 50% of available soil moisture range during 30 and 90 DAT (i.e. 43.7 and 34.6% of available soil moisture at 30 and 90 DAT, respectively) (Fig. 3). The increased soil evaporative loss along root water uptake from upper soil layers may be the reason for comparatively higher depletion of soil moisture in the control plot without mulching. This also points out the necessity of placing of two lateral lines in the raised beds for ensuring adequate moisture distribution in shallow rooted crops like onion., which is also supported by Li et al. [20].

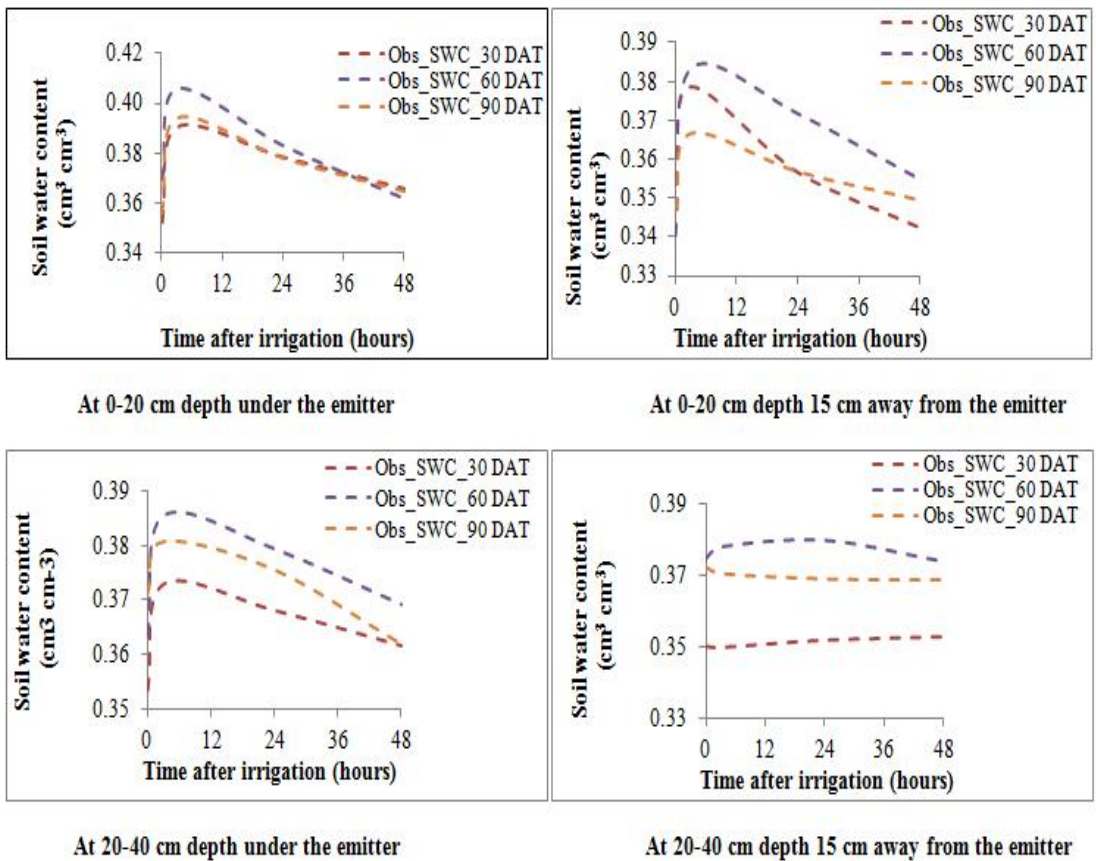


Fig. 1. Observed soil water content in paddy straw mulch treatment

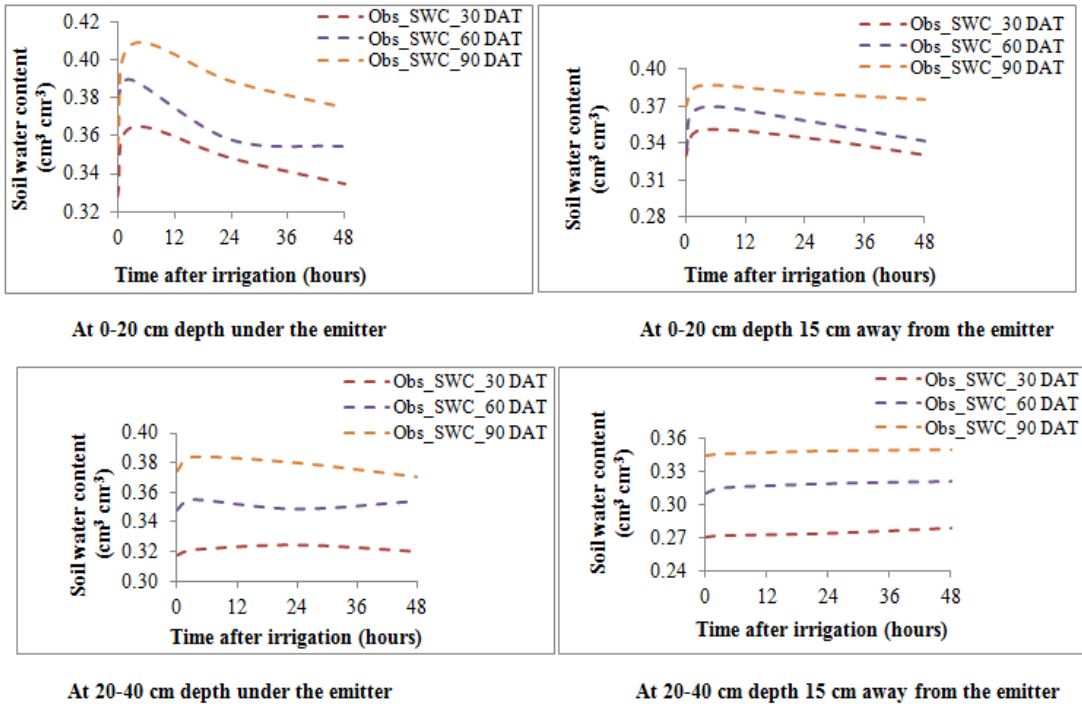


Fig. 2. Observed soil water content in white plastic mulch treatment

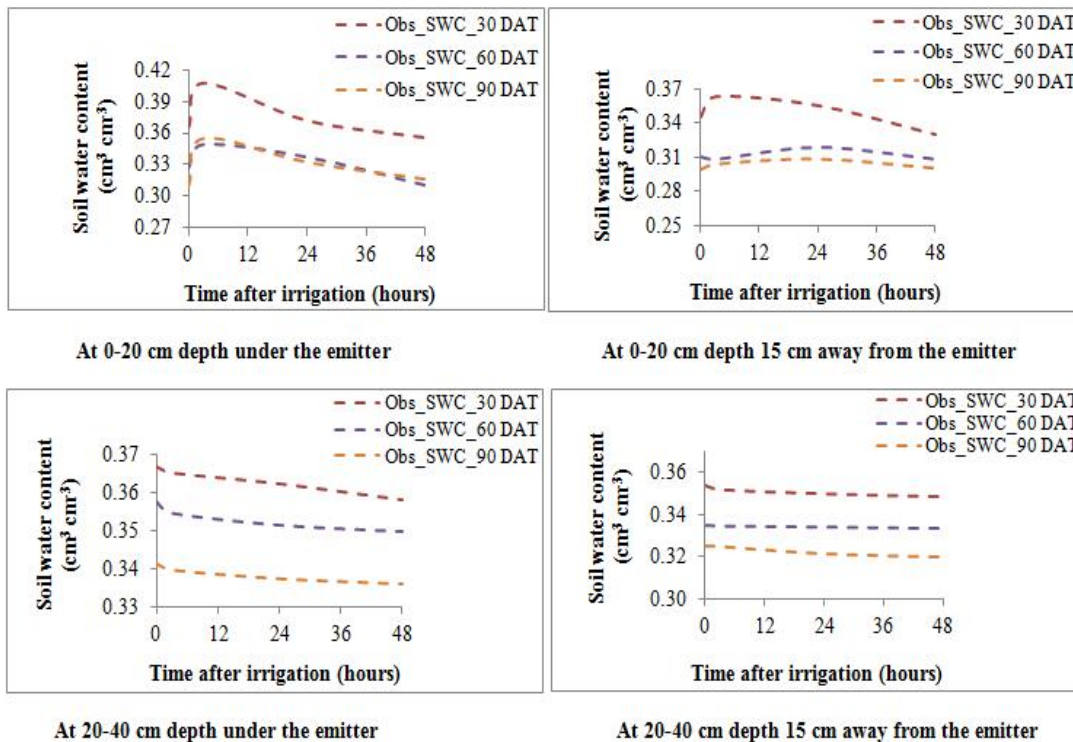


Fig. 3. Observed soil water content in control treatment

4. CONCLUSION

CROPWAT model was used for scheduling drip irrigation for onion crop in Vertisol soil under semi arid climatic condition. The total water requirement of onion crop was found 428.77 and 399.98 mm in 2018-19 and 2019-20 cropping seasons and same amount of irrigation was applied for onion under paddy straw mulch, white plastic mulch and control (bare soil) treatments. The soil moisture distribution in the crop root zone was monitored upto 48 hours after irrigation during different crop stages. The soil moisture remained within the available soil moisture range under the mulched treatments during the observation period, whereas the soil moisture depleted below available soil moisture range at 48 hours after irrigation in the control treatment. The soil moisture in the sub soil layers increased from 30 to 90 days after transplanting of the crop in the mulched treatments, while there was continuous depletion of soil moisture in the sub soil layers in control treatment indicating soil moisture evaporation due to capillary rise. The two days irrigation scheduling with the CROPWAT model for the onion crop in semi arid condition in Vertisol soil was sufficient to meet the crop water demand of the crop. CROPWAT model could be a good management tool for efficient irrigation scheduling for shallow rooted crop cultivation in semi arid condition, which also saves and improve the productivity of crops.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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